Issued January 25, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—BULLETIN 125.

HENRY S. GRAVES, Forester.

FORT VALLEY EXPERIMENT STATION.

THE COMPOSITE TYPE ON THE APACHE NATIONAL FOREST.

BY

HAROLD H. GREENAMYRE,

Forest Assistant.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

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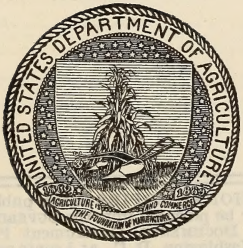

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Forest Service,
Washington, D. C., October 14, 1912.

Sir: I have the honor to transmit herewith a manuscript entitled "The Composite Type on the Apache National Forest," by Harold H. Greenamyre, Forest Assistant, and to recommend its publication as Bulletin 125 of the Forest Service.

Respectfully,

Henry S. Graves, *Forester.*

Hon. James Wilson,
Secretary of Agriculture.

Additional copies of this publication may be procured from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents per copy

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ILLUSTRATIONS.

THE COMPOSITE TYPE ON THE APACHE NATIONAL FOREST.

OBJECT OF THE STUDY.

A very unusual forest type in which western yellow pine, Douglas fir, and Colorado blue spruce occur in mixture has been found to exist in certain localities on the Apache and adjacent National Forests in southern Arizona. While western yellow pine (*Pinus ponderosa* Laws) and Douglas fir (*Pseudotsuga taxifolia* (Lam.) Britton) are both common throughout the Southwest, and are often found in mixture, the presence of Colorado blue spruce (*Picea parryana* (Andre) Parry), and especially its occurrence with western yellow pine, is extraordinary. Formerly this species was thought to grow only in the central Rocky Mountain States, for the most part along stream courses, and seldom in commercial quantities. Here, however, instead of growing typically along streams or in canyons, it is found on level or nearly level areas, mixed in varying proportion with western yellow pine and Douglas fir. The growth, side by side, of two species differing so widely in their requirements as blue spruce and western yellow pine points to unusual ecological conditions. This report, however, deals with growth, and no attempt will be made to explain the ecological factors responsible for the type. The study of the type, the results of which are given in this bulletin, was made in order that a plan of management for it could be included in the working plan for the forest.

THE TYPE.

EXTENT AND COMPOSITION.

The type is found mainly between altitudes of 8,750 and 9,200 feet, on the Blue and White Mountain Ranges of Arizona. The altitudinal limits are rather sharply defined, and a slight variation from them, with the accompanying change in temperature and rainfall, will completely change the type. Thus, below 8,750 feet the Douglas fir and spruce are almost entirely lacking, and the yellow pine grows in pure stand. Above 9,200 feet western yellow pine is seldom found, but Douglas fir and blue spruce are the prevailing species, either in mixture or in pure stands. Likewise, a difference in exposure or even in degree of slope within the limits of the type will cause a marked change. A sharp south slope, even toward the type's upper limits, will often be completely covered with western yellow pine, while a northern exposure near the lower limits may have a cover of spruce or fir with little or no western yellow pine.

In consequence, but few subtypes are found within the type proper. Practically the only variation is brought about by differences in proportion of the three species. This can not always be explained, though in some cases it is undoubtedly due to elevation. Curiously enough, the blue spruce extends at least 200 feet lower than the Douglas fir. This gives a basis for the distinction of one subtype in which only spruce and pine occur. This is always found at the lower altitudinal limits of the type. Two more subtypes may be distinguished. One is where Douglas fir and yellow pine are predominant, with but an occasional spruce in mixture. This subtype covers a small area, but may be found at any elevation throughout the type. The sparsity of blue spruce on these areas can not be explained. Within the other subtype Douglas fir and blue spruce predominate. This is found only at the upper limits of the type.

White fir (*Abies concolor* (Gord.) Parry) and Mexican white pine (*Pinus strobiformis* Engelm.) are occasionally found in mixture with the three principal species of the type. White fir, which occurs at the upper limits, is the most common. Engelmann spruce (*Picea engelmanni* Engelm.) is also found at higher elevations, along stream courses. Aspen is scattered here and there throughout the stand. Both it and Engelmann spruce are at present of no commercial importance in the region.

Since this combination of tree species is so exacting in the matter of site, it is found only in small bodies, which conform in a general way to the topography of the country. Probably about 150,000 acres in all on the Apache Forest is actually covered by the type.

Although conditions on other National Forests of New Mexico and Arizona are much the same as those on the Apache, this type is not known to occur elsewhere to any considerable extent except on that part of the Sitgreaves Forest which lies adjacent to the Apache, where it covers parts of 12 sections.

PROBABLE HISTORY.

Since blue spruce and western yellow pine differ so greatly in silvical requirements, it is improbable that they have grown side by side since early youth. There is every evidence that, while western yellow pine has undoubtedly occupied the ground for several generations, blue spruce has but recently come in. Indeed, the present stand of spruce is probably the first generation, a theory borne out by the fact that few decaying logs or old stumps of this species are to be found. The young spruce grows in dense groups beneath mother trees; but the oldest trees as a rule grow singly, very often on the north sides of western yellow pine, where the most protection was afforded.

In view of these observations it is believed that the stand has recently been and perhaps still is in a transitional stage. The present

mixed stand appears to be due to the influence of the original forest, composed of yellow pine alone or perhaps yellow pine and Douglas fir in mixture, which moderated conditions of light, temperature, and soil and air moisture to an extent which made possible the entrance of spruce.

Both the western yellow pine and the Douglas fir are older than the spruce, and the yellow-pine veterans range from 75 to 125 years older than those of the fir. All the spruce alive at present has come in within the last 150 years, most of it within the last 100 years. According to this the present yellow-pine veterans were over 200 years old and the Douglas fir over 100 years old when the spruce now present gained a foothold. On certain areas within the spruce-pine subtype all the spruce has entered within the last 50 years. Even here there is no evidence of a former generation of spruce.

AVERAGE STAND.

A stand survey of the composite type was made to determine accurately the number of trees per acre as well as the volume in board feet. Five plots selected in different localities throughout the type were taken as an average of the whole. The timber on these plots, which aggregated 500 acres, or approximately 0.3 per cent of the entire area covered by the type, was actually measured. All the trees of each species 4 inches diameter breast high and over were calipered and recorded by inch diameter classes.

Table 1 shows the average number of trees per acre by diameter classes for five species—white fir and Mexican white pine in addition to the three principal species of the type.

TABLE 1.—*Stand on sample acre of composite type.*

Diameter breast high.	Trees per acre.					
	Yellow pine.	Douglas fir.	Spruce.	White fir.	White pine.	All species.
Inches.						
4	1.42	1.80	1.19	0.08	0.61	5.1
5	1.72	1.89	1.55	.12	.52	5.5
6	1.71	1.70	1.48	.11	.45	5.4
7	1.68	1.52	1.33	.09	.40	5.0
8	1.67	1.39	1.52	.14	.34	5.0
9	1.48	1.36	1.19	.11	.30	4.4
10	1.44	1.16	1.14	.08	.26	4.1
11	1.33	1.11	.97	.08	.22	3.7
12	1.12	.89	.81	.09	.20	3.1
13	1.06	.91	.69	.06	.16	2.9
14	1.02	.73	.44	.09	.17	2.5
15	.93	.59	.38	.08	.12	2.1
16	.94	.53	.26	.08	.15	2.0
17	.83	.45	.23	.06	.15	1.7
18	.83	.48	.20	.06	.12	1.7
19	.77	.42	.12	.06	.12	1.5
20	.69	.38	.09	.05	.12	1.3
21	.65	.35	.07	.07	.12	1.3
22	.62	.34	.05	.07	.07	1.2
23	.52	.29	.04	.06	.09	1.0
24	.51	.29	.04	.06	.06	1.0
25	.49	.30	.02	.05	.07	.9
26	.40	.29	.01	.06	.08	.8
27	.44	.24	.02	.05	.05	.8
28	.38	.25	.01	.06	.06	.8

TABLE 1.—*Stand on sample acre of composite type*—Continued.

Diameter breast high.	Trees per acre.					
	Yellow pine.	Douglas fir.	Spruce.	White fir.	White pine.	All species.
Inches.						
29	.34	.26	.01	.05	.05	.7
30	.26	.22	.01	.04	.03	.6
31	.23	.20	.....	.04	.....	.5
32	.20	.22	.....	.03	.....	.4
33	.15	.20	.....	.03	.....	.3
34	.11	.16	.....	.03	.....	.3
35	.10	.17	.....	.03	.....	.3
36	.07	.15	.....	.02	.....	.2
37	.06	.10	.....	.02	.....	.2
38	.04	.13	.....	.02	.....	.2
39	.03	.10	.....	.02	.....	.1
40	.02	.08	.....	.01	.....	.1
Above 12 inches	12.69	8.93	2.69	1.36	1.79	27.5
Total	26.26	21.65	13.87	2.26	5.09	69.0
Per cent of whole	38.1.	31.4	20.1	3.2	7.2	100.0

It will be seen from the table that up to a diameter of 12 inches yellow pine, Douglas fir, and blue spruce are found in almost equal proportion. However, above this diameter the number of spruce per acre decreases rapidly, with practically none above 24 inches. Although spruce does not normally attain the size of yellow pine and Douglas fir, this bears out the opinion that the entrance of spruce within the type has been comparatively recent. The relative number of yellow pine and Douglas fir per acre varies but little. At a diameter of 4 inches, however, it is seen that Douglas fir predominates, a fact which would seem to indicate that the amount of Douglas fir reproduction is increasing. White fir and white pine are not at any time of first importance in the stand, though apparently the latter is rapidly increasing in numbers, and may gain a foothold at the expense of one of the more valuable species.

In computing the volume per acre of western yellow pine, Douglas fir, and blue spruce, volume tables constructed for these species within the composite type were used. Since no tables were available for white fir in this region, or for Mexican white pine, the table for Douglas fir was used in computing the volumes of the former, and the table for western yellow pine made by Woolsey on the Coconino Forest for the latter.

TABLE 2.—*Average per acre on composite type.*

	Board feet.
Western yellow pine	6,600
Douglas fir	5,450
Colorado blue spruce	350
White fir	850
Mexican white pine	850
Total average volume per acre, all species	14,100

While but 0.3 per cent of the estimated total area of the type was actually measured, it is believed that the resulting figures are fairly accurate, since the trees were calipered on measured areas, and in no case was reliance put in ocular estimates.

ECONOMIC IMPORTANCE.

There can be no question of the economic importance of the composite type, with its average yield of 14,100 board feet per acre, especially in the forests of Arizona and New Mexico, where typical stands of western yellow pine yield only from 4,000 to 7,000 board feet. Moreover, a combination of three species, each having different requirements, makes possible a complete utilization of the ground, thus satisfying one of the objects of silviculture—the production of the greatest possible amount of timber per unit area.

Economically, there is but little difference between Douglas fir and western yellow pine. Douglas fir has a much larger percentage of heartwood, and for some purposes will make better lumber. In the Southwest, however, there is a strong prejudice against the tree, though this can no doubt be overcome in the future. The spruce is largely sapwood, and because of this and its small size is of little value for lumber. It could, however, be utilized in mines after preservative treatment. The white pine fails to develop into a good timber tree, and the white fir, though often of good form, makes a poor grade of lumber. In the event of timber sales these secondary species could be utilized to some extent.

FUTURE COMPOSITION.

The reproductive capacity of the three chief species of the composite type is the most important factor in determining the probable composition of the forest after a cutting. Both spruce and Douglas fir bear cones at more frequent intervals and probably at an earlier age than western yellow pine. The interval between seed years of spruce is shorter than for the other species, and for this reason the total amount of seed produced is probably greater, though the germination per cent is no doubt considerably lower.

Here, as on most forests in the Southwest, the reproduction which succeeds in establishing itself is the result of a combination of good seed years and favorable climatic conditions. Seedlings of yellow pine establish themselves most readily in the larger openings, where they receive the necessary amount of light. The quantity of seed produced and the frequence of seed years are important factors, since the climatic conditions of every season are by no means favorable to the growth of seedlings. With yellow pine, good seed years occur at intervals of from three to five years. Blue spruce usually bears some seed each year; Douglas fir every second or third year.

Douglas fir and blue spruce, which are more tolerant, seldom if ever compete with yellow pine seedlings in the larger openings. These species germinate very well in dense shade, and will succeed in growing for some time with but little direct sunlight. Douglas fir seedlings are commonly found under mother trees, in aspen thickets, and under groups of yellow pine seedlings and saplings already large enough to cast an appreciable amount of shade. Blue

spruce seedlings are found usually on the north sides of mother trees and in dense thickets of spruce and Douglas fir, where there is a maximum amount of shade and, consequently, relatively lower temperature and more soil and air moisture.

The chief secondary species of the type—white pine and white fir—though not now competing with the more valuable species, may form a larger portion of the stand in the future, unless cutting is properly regulated. This is especially true of white pine, the quantity of which, as indicated in Table 1, seems to be increasing. It is believed that both species are somewhat less exacting as to light than are the principal ones. A succession of counts on reproduction plots proves that a larger proportion of white fir and white pine seedlings which germinate succeed in establishing themselves than do those of yellow pine, Douglas fir, and spruce. This is no doubt due in part to the large size of the seeds and to the exceptionally strong condition of the seedlings immediately after germination. Therefore, unless white fir and white pine are cut very close, there is danger that the composite type may undergo further changes, with a possibility of these two species predominating.

Aspen, though of no commercial value in the region at present, plays an important part in the composite type as a nurse tree. In spite of the fact that aspen is commonly classed as intolerant, it is found in considerable numbers even in the densest stands. Where the most light is received it usually occurs in groups, but in dense stands of the other species often grows singly. The protection afforded by a cover of aspen is excellent for the growth of Douglas fir and spruce in the seedling stage, and the shade does not retard the growth even of saplings. Western yellow pines occasionally start under aspen, which, by the time more light is required, die out, leaving the pine to develop unhampered.

COMPARATIVE GROWTH OF WESTERN YELLOW PINE, DOUGLAS FIR, AND BLUE SPRUCE.

Complete stem analyses data for each of the three principal species in the type form the basis for the growth studies outlined in the following pages. The fact that the trees were cut especially to secure this data made it possible to use great care in their selection as well as in that of the plots on which the cutting was done. For this reason it is believed that the comparatively small number of trees on which complete stem analyses were obtained is sufficient, and that the resulting tables accurately represent the growth in virgin stands.

The cutting was done in two localities on eight sample plots, varying in size from 1 to 2 acres. Different subtypes, as well as stands of different density, were represented. Only normal trees were selected for analysis, which was conducted in accordance with the usual method. In the case of trees under 12 inches in diameter the stems

were cut into sections varying in length from 2.5 to 10 feet, depending upon the total length of the tree. Each stem was cut into at least three sections. With the trees above 12 inches, cuts were made at intervals of from 10 to 14 feet. The growth data were worked up graphically, according to the method described by Mlodjiansky,[1] and later modified by Graves.[2]

To obtain data for a comparison of the growth of western yellow pine in the two forest types, 110 counts were made on yellow pine stumps of different diameters on a timber sale in the pure yellow pine type. Measurements of clear length and total height were also taken on 800 western yellow pines in each type.

DIAMETER.

The diameter growth, based upon age, of western yellow pine, Douglas fir, and blue spruce is shown in Table 3. It will be seen that the greatest actual diameter growth for yellow pine and Douglas fir occurs at practically the same period, between the ages of 50 and 130 years. The greatest actual diameter growth of blue spruce occurs earlier in the life of the tree, between 30 and 90 years.

TABLE 3.—*Diameter growth of western yellow pine, Douglas fir, and blue spruce.*[3]

Age.	Diameter breast high outside bark.		
	Pine.	Fir.	Spruce.
Years.	*Inches.*	*Inches.*	*Inches.*
10	0.6	0.6	0.4
20	1.3	1.4	1.1
30	2.2	2.3	2.2
40	3.4	3.4	3.8
50	4.6	4.6	6.0
60	6.0	6.0	9.2
70	7.5	7.4	12.3
80	9.0	9.0	14.8
90	10.5	10.6	16.8
100	12.0	12.2	18.4
110	13.4	13.9	19.8
120	14.8	15.6	21.0
130	16.2	17.2	22.0
140	17.5	18.8	22.8
150	18.8	20.4	23.5
160	20.0	22.0	.....
170	21.2	23.5	.....
180	22.4	25.0	.....
190	23.6	26.4	.....
200	24.7	27.7	.....
210	25.8	28.9	.....
220	26.9	30.1	.....
230	27.9	31.2	.....
240	28.9	32.1	.....
250	29.8	33.1	.....
260	30.6	34.0	.....
270	31.4	34.8	.....
280	32.2	35.6	.....
290	32.9	36.4	.....
300	33.5	37.2	.....
310	34.1	37.8	.....
320	34.7	38.4	.....
330	35.2	.....	.....
340	35.7	.....	.....
350	36.2	.....	.....
360	36.6	.....	.....

[1] Forest Service Bulletin 20, "Measuring the Forest Crop."

[2] "Forest Mensuration."

[3] Based on stem analyses of 180 western yellow pine, 185 Douglas fir, and 135 blue spruce.

A glance at figure 1 or a study of Table 3 shows the growth of spruce after the period of early youth is passed to be the greatest of the three. In the case of spruce, however, the maximum is reached at an earlier period in the life of the tree and the growth falls off sooner than in the case of the two other species. The diameter growth of western yellow pine and Douglas fir is practically the same until

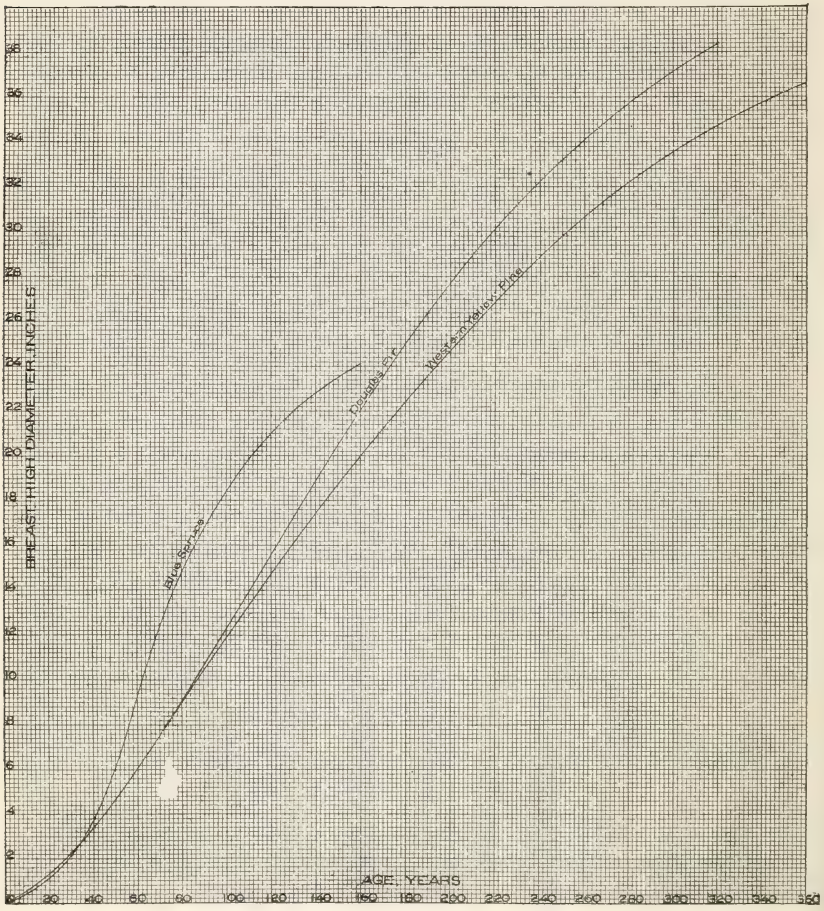

FIG. 1.—Growth in diameter in relation to age of western yellow pine, Douglas fir, and blue spruce.

the age of 100 years is reached, when Douglas fir gradually forges ahead. The curves show at what ages the rate of growth of the three species begins to decline. Blue spruce noticeably falls off in diameter growth at 100 years of age. The growth of yellow pine is well sustained until it is 180 years old, and that of Douglas fir for 40 years longer.

HEIGHT.

The height growth of western yellow pine, Douglas fir, and blue spruce is shown in Table 4. Both the height of the tree at each decade and the periodic annual height growth are given. As in the case of diameter growth, the maximum height growth of western yellow pine and Douglas fir is reached at about the same time, approximately at the age of 70 years. Spruce also reaches its maximum height growth at an age of from 60 to 70 years, when the periodic annual height amounts to 1.24 feet, or almost twice that for yellow pine.

TABLE 4.—*Height growth of western yellow pine, Douglas fir, and blue spruce.*[1]

Age.	Height.			Periodic annual height growth.		
	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.
Years.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
10	2.2	1.3	1.5	0.22	0.13	0.15
20	5.0	4.1	4.0	.28	.28	.25
30	9.0	9.0	7.0	.40	.49	.30
40	13.6	15.4	14.0	.46	.64	.70
50	19.4	22.8	23.0	.58	.74	.90
60	26.0	30.2	34.3	.66	.74	1.13
70	33.1	37.7	46.7	.71	.75	1.24
80	40.2	44.6	58.0	.71	.69	1.13
90	47.2	51.1	69.0	.70	.65	1.10
100	54.0	57.4	78.0	.68	.63	.90
110	60.0	63.3	86.0	.60	.59	.80
120	65.5	68.8	92.0	.55	.55	.60
130	70.5	73.8	98.0	.50	.50	.60
140	75.1	78.6	104.0	.46	.48	.60
150	79.3	83.0	108.0	.42	.44	.40
160	83.1	87.1	.....	.38	.41	.....
170	86.9	91.0	.....	.38	.39	.....
180	90.0	94.5	.....	.31	.35	.....
190	93.0	97.8	.....	.30	.33	.....
200	95.9	101.0	.....	.29	.32	.....
210	98.2	103.6	.....	.23	.26	.....
220	100.4	106.1	.....	.22	.25	.....
230	102.3	108.2	.....	.19	.21	.....
240	104.1	110.0	.....	.18	.18	.....
250	105.8	111.5	.....	.17	.15	.....
260	107.2	112.9	.....	.14	.14	.....
270	108.5	114.0	.....	.13	.11	.....
280	109.6	114.9	.....	.11	.09	.....
290	110.6	115.7	.....	.10	.08	.....
300	111.3	116.3	.....	.07	.06	.....
310	111.9	116.9	.....	.06	.06	.....
320	112.4	117.4	.....	.05	.05	.....
340	112.8	.....	.....	.04	.....	.....
350	113.4	.....	.....	.03	.....	.....
360	113.6	.....	.....	.02	.....	.....

It will be noticed from figure 2 that in early youth the spruce and fir grow more slowly than the pine. This is partly explained by the fact that during that period these species frequently grow under cover. However, both spruce and fir finally pass the pine and lead it during the remainder of life. Spruce also outgrows Douglas fir in height after the age of 44 years, and at 150 years is 25 feet taller than

[1] Based on the complete stem analyses of 180 western yellow pine, 185 Douglas fir, and 135 blue spruce.

Douglas fir, and almost 30 feet taller than western yellow pine. The greatest difference in height between yellow pine and Douglas fir occurs at 240 years, when the latter species is 6 feet taller.

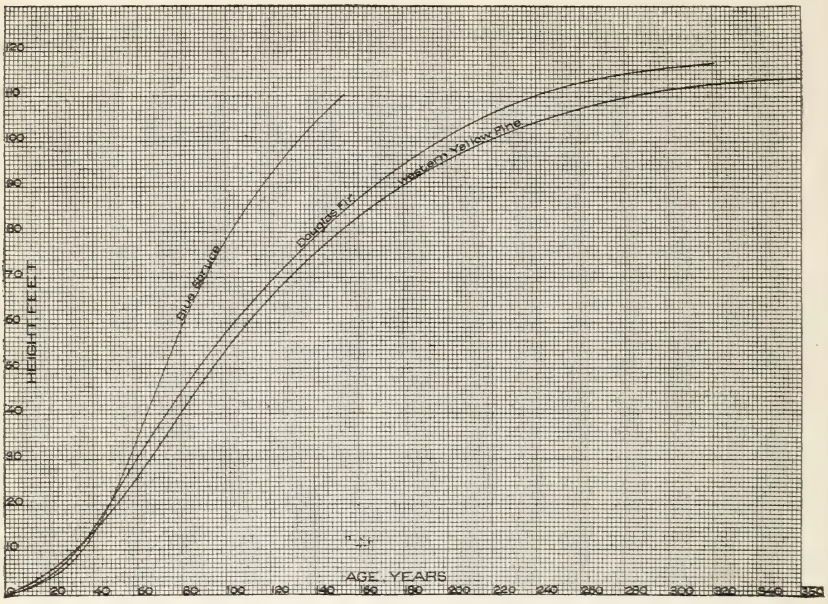

FIG. 2.—Relation of height growth to age of western yellow pine, Douglas fir, and blue spruce.

VOLUME.

Table 5, made from curves constructed upon the basis of age, shows the growth in volume of western yellow pine, Douglas fir, and blue spruce. For each diameter class above 12 inches is given the age, the number of years required to grow 1 inch in diameter, the number of 16-foot logs, and the volume in both board and cubic feet.[1]

[1] While this is not the method in general use for making volume tables, it is thought that the resulting figures are correct. Diameter age curves were drawn on the basis of age for each crosscut and all the curves of the tree entered on the same cross-section paper. The stump curve has its zero point at the intersection of the vertical and horizontal axes of the rectangular coordinates. The curve for the second crosscut has its zero on the horizontal axis to the right at the age required by the trees to grow from the ground to this crosscut. (This is determined from a preliminary age height curve.) The curve for the third crosscut is still further to the right at the age required to grow from the ground to this crosscut. The other curves are entered on the sheet in like manner.

From the resulting diagram the dimensions of different cross sections at various breast-high diameters or ages may readily be determined.

TABLE 5.—*Volume growth of western yellow pine, Douglas fir, and blue spruce.*

Diameter breast high (outside bark).	Age.			Time required to grow 1 inch in diameter.			Number of 16-foot logs.			Volume.					
	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.	Pine.		Fir.		Spruce.	
										Bd. ft.	Cu. ft.[1]	Bd. ft.	Cu. ft.	Bd. ft.	Cu. ft.
Ins.	*Yrs.*	*Yrs.*	*Yrs.*	*Yrs.*	*Yrs.*	*Yrs.*									
12	100	99	69	.....	.....	.....	1.2	1.1	1.0	40	15.32	30	14.98	30	13.80
13	107	105	72	7	6	3	1.5	1.4	1.0	50	19.60	50	18.88	30	16.12
14	114	111	76	7	6	4	2.0	1.7	1.0	90	24.63	80	23.07	30	19.50
15	122	117	81	8	6	5	2.2	2.0	1.3	120	31.08	100	27.83	50	23.87
16	129	123	86	7	6	5	2.5	2.2	1.5	150	37.57	120	32.78	70	28.77
17	136	129	91	7	6	5	2.8	2.5	1.8	190	44.66	150	38.14	90	33.76
18	144	135	97	8	6	6	3.1	2.8	2.0	220	53.02	180	44.14	110	40.13
19	152	141	104	8	6	7	3.5	3.0	2.4	310	61.87	190	50.37	150	48.00
20	160	147	111	8	6	7	3.7	3.2	3.0	360	71.78	240	57.10	200	56.19
21	168	153	120	8	6	9	4.0	3.4	3.2	430	82.24	310	63.11	260	66.72
22	176	160	130	8	7	10	4.1	3.6	3.6	500	92.86	340	71.62	360	77.98
23	184	166	142	8	6	12	4.3	3.8	4.0	580	103.91	380	79.35	420	89.85
24	193	173	.....	9	7	.....	4.5	4.0	.....	610	117.00	430	88.55	.....	.....
25	202	180	.....	9	7	.....	4.6	4.1	.....	710	130.44	500	97.98	.....	.....
26	211	187	.....	9	7	.....	4.9	4.2	.....	810	143.45	560	107.82	.....	.....
27	220	194	.....	9	8	.....	5.0	4.4	.....	920	158.16	640	117.88	.....	.....
28	230	202	.....	10	8	.....	5.1	4.6	.....	1,040	173.66	720	129.67	.....	.....
29	241	210	.....	11	8	.....	5.3	4.8	.....	1,150	189.94	800	141.77	.....	.....
30	252	219	.....	11	9	.....	5.5	5.0	.....	1,250	206.76	900	155.81	.....	.....
31	264	229	.....	12	10	.....	5.7	5.1	.....	1,420	225.25	1,020	171.74	.....	.....
32	277	239	.....	13	10	.....	5.8	5.3	.....	1,530	241.19	1,130	187.99	.....	.....
33	292	249	.....	15	11	.....	6.0	5.5	.....	1,720	266.88	1,220	204.48	.....	.....
34	308	260	.....	16	11	.....	6.1	5.6	.....	1,880	288.68	1,370	222.85	.....	.....
35	326	272	.....	18	12	.....	6.2	5.8	.....	2,060	312.18	1,480	242.47	.....	.....
36	346	285	.....	20	13	.....	6.4	6.0	.....	2,250	336.13	1,680	263.04	.....	.....
37	.....	298	.....	.....	13	.....	.....	6.1	.....	.....	.....	1,840	282.82	.....	.....
38	.....	312	.....	.....	13	.....	.....	6.2	.....	.....	.....	1,960	302.84	.....	.....

[1] Each log is cubed according to Smalian's formula. The top above a point 8 inches in diameter is cubed as a cone and the stump as a cylinder.

To reach a diameter of 12 inches, western yellow pine and Douglas fir require 100 and 99 years, respectively, while spruce requires only 69 years. At 110 years the spruce is still making a good growth, but soon after this it falls off rather rapidly, and maturity is probably reached not long after it is 150 years old. Further proof of this is found in a comparison of the number of years required to increase 1 inch in diameter. At 12 inches spruce increases an inch in diameter in 3 years, while it takes pine and fir 7 and 6 years, respectively. But with an increase in age in spruce there is a corresponding increase in the length of time required to grow 1 inch, while for pine and fir this period remains practically the same up to 180 years.

In comparing the number of 16-foot logs (top diameter of 8 inches) which the different species will cut at a given diameter, it is found that western yellow pine leads both fir and spruce, in spite of the fact that the latter species makes a faster growth in both diameter and height. The explanation lies in the difference in form of bole and thickness of bark. Although spruce has a thin bark, the stem tapers very rapidly and quite evenly throughout its entire length. Occasionally it is swell-butted. The bark of Douglas fir is much thicker than that of either spruce or pine, and, like spruce, the bole does not "fill out," but has a considerable taper, even in old age. In

addition to this it is often swell-butted. The pine has medium thick bark, but comparatively little taper, and the bole, especially at old age, fills out well.

The difference in volume is even more pronounced than the difference in merchantable length. Spruce, on account of its great taper, produces no merchantable log until it reaches a diameter of 14 inches. At this diameter western yellow pine has a merchantable

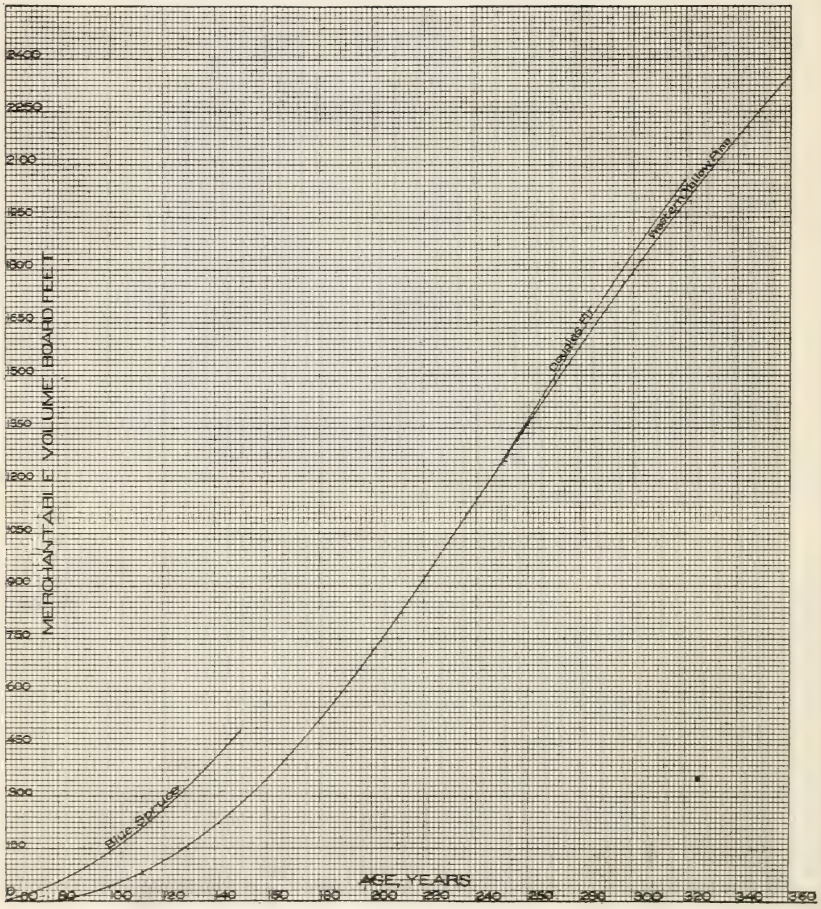

FIG. 3.—Growth in volume of western yellow pine, Douglas fir, and blue spruce.

length twice as great, and Douglas fir nearly as much. A better comparison of the volumes can be obtained if age is taken as a basis.

Table 6 gives the volume of each species in both board and cubic measure at 10-year intervals. On account of the inaccuracies in the decimal "C" rule, or in fact, in any board foot measure, a more exact comparison of the three species may be made from the columns headed "Volume, cubic feet."

TABLE 6.—*Volume growth of western yellow pine, Douglas fir, and blue spruce.*

Age.	Diameter breast high outside bark.			Number 16-foot logs 8-inch top diameter limit.			Merchantable volume.			Total volume.		
	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.
Years.	*Ins.*	*Ins.*	*Inches.*				*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
10	0.6	0.6	0.4	.....	.....	.....	.....	.....	.....	.....	.....	.....
20	1.3	1.4	1.1	.....	.....	.....	.....	.....	.....	0.02	0.02	0.02
30	2.2	2.3	2.2	.....	.....	.....	.....	.....	.....	.10	.11	.10
40	3.4	3.4	3.8	.....	.....	.....	.....	.....	.....	.35	.37	.46
50	4.6	4.6	6.0	.....	.....	.....	.....	.....	.....	.84	.96	1.74
60	6.0	6.0	9.2	.....	.....	.....	.....	.....	.....	1.86	2.12	5.92
70	7.5	7.4	12.3	.....	.....	.....	.....	.....	.....	3.63	3.98	13.54
80	9.0	9.0	14.8	.....	.....	1.2	.....	.....	50	6.85	6.73	21.23
90	10.5	10.6	16.8	.....	.....	1.7	.....	.....	100	10.56	10.45	30.20
100	12.0	12.2	18.4	1.1	1.2	2.2	40	30	150	15.32	15.49	39.24
110	13.4	13.9	19.8	1.6	1.7	2.8	80	70	200	21.56	22.28	50.16
120	14.8	15.6	21.0	2.1	2.1	3.2	110	110	260	29.23	30.11	61.36
130	16.2	17.2	22.0	2.6	2.6	3.6	150	150	360	38.51	39.03	73.13
140	17.5	18.8	22.8	3.0	3.0	3.9	210	210	390	48.77	49.25	85.10
150	18.8	20.4	23.5	3.3	3.3	4.1	270	270	440	59.40	59.47	97.27
160	20.0	22.0	.....	3.6	3.6	.....	360	340	.....	71.79	71.63	.....
170	21.2	23.5	.....	3.9	3.9	.....	430	430	.....	84.86	84.51	.....
180	22.4	25.0	.....	4.2	4.1	.....	510	500	.....	98.21	97.98	.....
190	23.6	26.4	.....	4.4	4.3	.....	600	600	.....	112.47	112.04	.....
200	24.7	27.7	.....	4.6	4.5	.....	720	710	.....	127.58	126.65	.....
210	25.8	28.9	.....	4.8	4.7	.....	810	800	.....	142.83	141.77	.....
220	26.9	30.1	.....	5.0	4.9	.....	920	920	.....	158.17	157.37	.....
230	27.9	31.2	.....	5.1	5.1	.....	1,040	1,020	.....	173.67	173.34	.....
240	28.9	32.1	.....	5.3	5.3	.....	1,130	1,130	.....	189.32	189.62	.....
250	29.8	33.1	.....	5.4	5.4	.....	1,220	1,230	.....	204.05	206.13	.....
260	30.6	34.0	.....	5.6	5.6	.....	1,400	1,370	.....	219.94	222.85	.....
270	31.4	34.8	.....	5.7	5.7	.....	1,470	1,460	.....	235.67	239.27	.....
280	32.2	35.6	.....	5.8	5.9	.....	1,550	1,620	.....	250.99	255.28	.....
290	32.9	36.4	.....	6.0	6.0	.....	1,680	1,730	.....	265.81	270.82	.....
300	33.5	37.2	.....	6.1	6.1	.....	1,780	1,840	.....	280.04	285.82	.....
310	34.1	37.8	.....	6.2	6.2	.....	1,920	1,940	.....	293.46	300.13	.....
320	34.7	38.3	.....	6.2	6.2	.....	1,990	2,030	.....	306.55	313.72	.....
330	35.2	.....	.....	6.3	.....	.....	2,090	.....	.....	319.20	.....	.....
340	35.7	.....	.....	6.4	.....	.....	2,160	.....	.....	331.21	.....	.....
350	36.2	.....	.....	6.4	.....	.....	2,270	.....	.....	342.68	.....	.....
360	36.6	.....	.....	6.5	.....	.....	2,350	.....	.....	353.55	.....	.....

COMPARATIVE FORM FACTORS.

Table 7, which is based upon age, gives for each decade after a merchantable size is reached the form factors for western yellow pine, Douglas fir, and blue spruce. In addition, the total height and diameter are shown at each 10-year interval.

TABLE 7.—*Form factors of western yellow pine, Douglas fir, and blue spruce.*[1]

Age.	Height.			Diameter breast high, outside bark.			Merchantable form factor.[2]		
	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.
Years.	*Feet.*	*Feet.*	*Feet.*	*Inches.*	*Inches.*	*Inches.*			
10	2.2	1.3	1.5	0.6	0.6	0.4	.....	.....	.....
20	5.0	4.1	4.0	1.3	1.4	1.1	.....	.....	.....
30	9.0	9.0	7.0	2.2	2.3	2.2	.....	.....	.....
40	13.6	15.4	14.0	3.4	3.4	3.8	.....	.....	.....
50	19.4	22.8	23.0	4.6	4.6	6.0	.....	.....	.....
60	26.0	30.2	34.3	6.0	6.0	9.2	.....	.....	.....
70	33.1	37.7	46.7	7.5	7.4	12.3	.....	.....	.....
80	40.2	44.6	58.0	9.0	9.0	14.8	.....	.....	0.219
90	47.2	51.1	69.0	10.5	10.6	16.8	.....	.....	.234
100	54.0	57.4	78.0	12.0	12.2	18.4	0.245	0.229	.236
110	60.0	63.3	86.0	13.4	13.9	19.8	.281	.239	.248
120	65.5	68.8	92.0	14.8	15.6	21.0	.313	.281	.259
130	70.5	73.8	98.0	16.2	17.2	22.0	.332	.283	.265
140	75.1	78.6	104.0	17.5	18.8	22.8	.350	.290	.268
150	79.3	83.0	108.0	18.8	20.4	23.5	.356	.290	.273
160	83.1	87.1	.....	20.0	22.0	.....	.366	.288	.....
170	86.9	91.0	.....	21.2	23.5	.....	.371	.287	.....
180	90.0	94.5	.....	22.4	25.0	.....	.376	.285	.....
190	93.0	97.8	.....	23.6	26.4	.....	.377	.284	.....
200	95.9	101.0	.....	24.7	27.7	.....	.379	.284	.....
210	98.2	103.6	.....	25.8	28.9	.....	.381	.287	.....
220	100.4	106.1	.....	26.9	30.1	.....	.381	.290	.....
230	102.3	108.2	.....	27.9	31.2	.....	.381	.290	.....
240	104.1	110.0	.....	28.9	32.1	.....	.382	.295	.....
250	105.8	111.5	.....	29.8	33.1	.....	.383	.298	.....
260	107.2	112.9	.....	30.6	34.0	.....	.384	.302	.....
270	108.5	114.0	.....	31.4	34.8	.....	.387	.307	.....
280	109.6	114.9	.....	32.2	35.6	.....	.389	.310	.....
290	110.6	115.7	.....	32.9	36.4	.....	.391	.313	.....
300	111.3	116.3	.....	33.5	37.2	.....	.395	.316	.....
310	111.9	116.9	.....	34.1	37.8	.....	.398	.320	.....
320	112.4	117.4	.....	34.7	38.4	.....	.400	.325	.....
330	112.8	.....	.....	35.2	.....	.....	.405	.....	.....
340	113.1	.....	.....	35.7	.....	.....	.407	.....	.....
350	113.4	.....	.....	36.2	.....	.....	.409	.....	.....
360	113.6	.....	.....	36.6	.....	.....	.411	.....	.....

[1] Based on the measurements of 180 western yellow pines; 185 Douglas fir; and 135 blue spruce.
[2] The form factors are based on the volume of wood over 8 inches in diameter. The volume of the stump is not included.

It is interesting to note the manner in which the form factors given in Table 7 vary with the increase in age of the tree. This is true for each species and shows the difference in the form of the tree at youth and at maturity. In fact, the greatest difference in the three species is found in the form of the bole. At no age do the form factors for the three species closely correspond, although at 100 years pine and fir are comparatively close. The form factor for yellow pine at 100 years of age is 0.245. From this point it increases steadily with the age of the tree until at 360 years it is 0.411. The form factor for Douglas fir at 100 years is even lower than that for pine, and remains so throughout the life of the tree. At the age of 320 years it is 0.325. Since breast-high measurements were used in computing the cubical contents of the trees for use in determining the form factors, the small figures for Douglas fir are due only to a very slight extent to butt swell. Spruce resembles Douglas fir in form of bole, although it is somewhat more tapering. The indications are that this species will not fill out as much as either yellow pine or Douglas fir even at maturity.

COMPARATIVE INCREMENT.

Table 8 gives the increment growth of western yellow pine, Douglas fir, and blue spruce. The mean annual growth, the periodic annual growth, and the periodic annual growth per cent are shown at each decade.

TABLE 8.—*Increment of western yellow pine, Douglas fir, and blue spruce.*[1]

Age.	Mean annual growth.			Periodic annual growth.[2]					
	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.	Pine.	Fir.	Spruce.
Years.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Per ct.*	*Per ct.*	*Per ct.*
10	0.0003	0.0002	0.0002	0.0003	0.0002	0.0002	.....	.....	.....
20	.0011	.0011	.0009	.0019	.0021	.0015	15.20	16.80	15.89
30	.0033	.0036	.0034	.0077	.0085	.0085	12.72	12.97	14.28
40	.0086	.0092	.0115	.0247	.0261	.0358	11.10	10.96	12.71
50	.0167	.0192	.0347	.0490	.0589	.1276	8.29	8.88	11.61
60	.0309	.0353	.0986	.1019	.1159	.4180	7.57	7.53	10.92
70	.0518	.0568	.1935	.1777	.1860	.7527	6.47	6.10	7.73
80	.0856	.0841	.2641	.3221	.2756	.7687	6.14	5.14	4.42
90	.1173	.1161	.3355	.3710	.3719	.8972	4.26	4.32	3.48
100	.1532	.1549	.3924	.4459	.5039	.9036	3.39	3.88	2.60
110	.1960	.2025	.4560	.6242	.6790	1.0921	3.38	3.59	2.44
120	.2436	.2509	.5113	.7668	.7932	1.1203	3.02	3.03	2.01
130	.2966	.3002	.5625	.9274	.8920	1.1764	2.73	2.58	1.74
140	.3483	.3518	.6078	1.0264	1.0220	1.1975	2.35	2.31	1.51
150	.3959	.3964	.6484	1.1028	1.1217	1.2166	2.04	2.06	1.33
160	.4486	.4476	.....	1.1987	1.2159	.....	1.80	1.85	.....
170	.4991	.4971	.....	1.3074	1.2883	.....	1.66	1.65	.....
180	.5455	.5443	.....	1.3347	1.3472	.....	1.46	1.47	.....
190	.5920	.5897	.....	1.4263	1.4059	.....	1.35	1.33	.....
200	.6379	.6332	.....	1.5112	1.4603	.....	1.26	1.22	.....
210	.6801	.6751	.....	1.5250	1.5123	.....	1.12	1.12	.....
220	.7185	.7156	.....	1.5337	1.5603	.....	1.01	1.04	.....
230	.7550	.7536	.....	1.5499	1.5972	.....	.93	.96	.....
240	.7888	.7900	.....	1.5654	1.6272	.....	.86	.89	.....
250	.8162	.8245	.....	1.5730	1.6514	.....	.79	.83	.....
260	.8459	.8571	.....	1.5893	1.6721	.....	.74	.78	.....
270	.8728	.8861	.....	1.5730	1.6415	.....	.69	.71	.....
280	.8963	.9117	.....	1.5315	1.6013	.....	.62	.65	.....
290	.9165	.9338	.....	1.4821	1.5536	.....	.57	.59	.....
300	.9334	.9527	.....	1.4226	1.5009	.....	.52	.53	.....
310	.9466	.9681	.....	1.3422	1.4304	.....	.46	.48	.....
320	.9579	.9803	.....	1.3087	1.3591	.....	.43	.44	.....
330	.9675	.....	.....	1.2650	.....	.....	.40	.....	.....
340	.9741	.....	.....	1.2017	.....	.....	.37	.....	.....
350	.9790	.....	.....	1.1465	.....	.....	.34	.....	.....
360	.9820	.....	.....	1.0870	.....	.....	.31	.....	.....

[1] Based on the measurements of 180 western yellow pines, 185 Douglas fir, and 135 blue spruce.

[2] The periodic annual growth per cent was computed by the formula $p=\frac{V-v}{V+v}\times\frac{200}{n}$, in which "p" is the rate per cent, "V" the present volume, "v" that "n" years ago, and "n" the number of years in the period which in this case is 10.

From this table it is seen that up to the age of 280 years there is very little difference in the mean annual growth of western yellow pine and Douglas fir. But after this the fir takes the lead, and at the age of 320 years its mean annual growth is almost as great as that of pine when the latter species is 40 years older. At the age of 40 years the mean annual growth of spruce increases over that of pine and fir, until at 150 years it is more than one-third greater.

Since there is a difference in the three species in respect to mean annual growth, there is a corresponding difference in respect to periodic annual growth. However, this difference is not great in the case of spruce at the age of 150 years; this is because the growth

was much faster than that of the other two species in early life. Also, judging from the slight increase in the periodic annual growth of spruce between 100 and 150 years, it is near the point of culmination. It is seen that the maximum periodic annual growth of yellow pine and Douglas fir is reached at approximately the same time, at 260 years. For the last 60 years, however, this has been increasing very slowly. In spruce the maximum periodic annual growth does not occur until some time after 140 years. It, too, is increasing slowly, and from the indications its maximum will be reached at an age not to exceed 180 years.

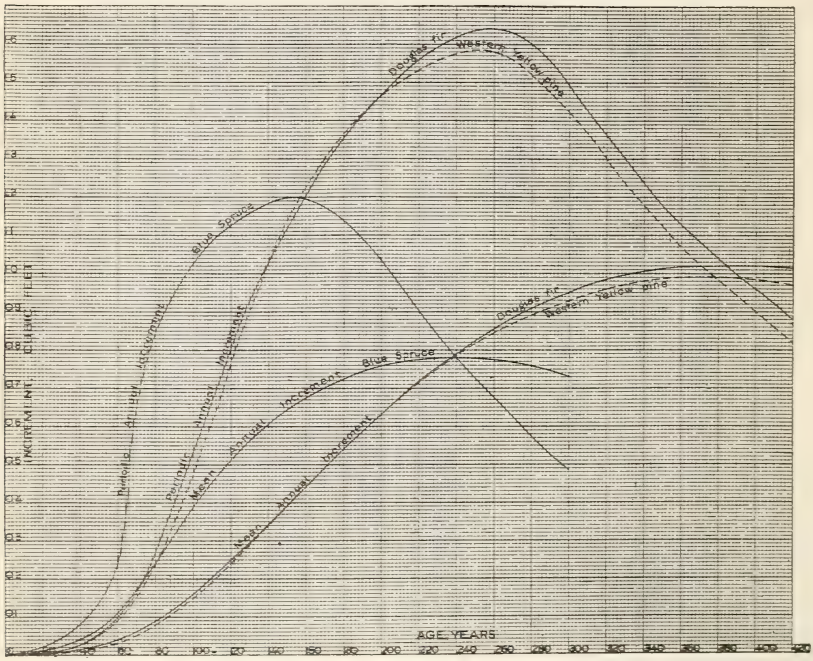

FIG. 4.—Increment growth of western yellow pine, Douglas fir, and blue spruce.

At the age of 320 years in Douglas fir and at 360 years in yellow pine, the mean annual increment does not yet equal the periodic annual increment. In spruce there is a great difference between the two at 150 years. As may be seen in Figure 4, the curves representing the periodic annual increment cross the curves representing the mean annual increment at the age of 377 years in western yellow pine, at 383 years in Douglas fir, and at 240 years in blue spruce. In each case the mean annual growth reaches its maximum at this point. It may also be seen that after this time the periodic annual increment decreases more rapidly than the mean annual increment.

A study of the columns headed "Periodic annual growth, per cent," will give an idea of the amount of wood laid on in relation to the size of the tree. It may be seen that this is at its maximum in the early stages of development, and decreases steadily as the trees grow older. The different species are alike in this respect. Since the mean and periodic annual growth of western yellow pine and Douglas fir correspond closely, there is but little difference in the two species in respect to the annual growth per cent. Since both the mean annual and periodic annual growth of spruce are greater than those of either pine or fir, it would seem at first sight that the periodic annual growth per cent would also be greater, though, in fact, it is found to be much less. This is explained by the fact that a greater growth is made early in life, and inasmuch as the principal is larger the rate of growth in per cent is small, even though the periodic annual growth or interest is large.

COMPARATIVE GROWTH OF WESTERN YELLOW PINE IN PURE AND IN COMPOSITE STANDS.

Since there was an apparent difference between both the height and clear length of western yellow pine in the composite type and in the western yellow-pine type, measurements were taken on a total of 1,600 trees for comparison. The results are expressed in Table 9, which gives the age, clear length, and total height in the two forest types at each inch diameter class from 12 to 36. At a diameter of 12 inches the ages are practically the same; but from this point the relative time required for trees in the yellow-pine type to grow one inch in diameter increases, until at 28 inches it is almost three times as great as for trees in the composite type. At this diameter there is a difference of more than 100 years in the total age of trees in the two types.

The difference in clear length corresponds very closely to the difference in total height. At a breast-high diameter of 12 inches the clear length of trees in the composite type is 23 feet, and in the yellow-pine type but 7 feet. The difference steadily increases until at 36 inches it is 25 feet in favor of the composite type. Trees in the yellow-pine type are but 49 feet tall at a diameter of 12 inches; at the same diameter and at approximately the same age, trees in the composite type are 65 feet tall. The difference in height is slightly greater at a diameter of 36 inches.

TABLE 9.—*Age, clear length, and total height in relation to diameter of western yellow pine in two forest types.*

Diameter breast-high, outside bark.	Age.		Clear length.[1]		Total height.	
	Composite type.	Yellow-pine type.[2]	Composite type.	Yellow-pine type.	Composite type.	Yellow-pine type.
Inches.	*Years.*	*Years.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
12	100	98	23	7	65	49
13	107	107	25	9	69	53
14	114	116	27	10	72	57
15	122	126	29	12	76	60
16	129	136	31	13	79	63
17	136	147	33	14	83	66
18	142	159	34	16	86	69
19	152	172	36	17	88	71
20	160	184	37	18	91	74
21	168	199	38	18	93	76
22	176	214	40	19	96	78
23	184	230	40	20	98	80
24	193	247	42	20	100	82
25	202	266	43	21	102	84
26	211	286	43	21	103	85
27	220	310	44	22	105	86
28	230	339	45	22	106	88
29	241	.....	45	22	107	89
30	252	.....	46	22	108	90
31	264	.....	46	23	109	90
32	277	.....	47	23	110	91
33	292	.....	47	23	111	92
34	307	.....	47	23	112	92
35	325	.....	48	23	112	93
36	344	.....	48	23	112	93

[1] Distance from ground to first green limb.
[2] Stem analyses for trees above 28 inches in the yellow-pine type are not at hand.

The faster growth in the composite type is due to more favorable site and climatic conditions. Since this type is found usually on level areas, very little of it is subject to extreme exposure. In addition, the dense forest cover protects the soil and checks evaporation. The precipitation, especially snowfall, because of the higher elevation, is greater in the composite type than in the pure yellow-pine type.

The difference in height growth in the two types is especially striking. It is due in part to the superior site quality of the composite type; but the greater density of stand is probably of the most importance. Since only a small amount of light is received from the sides, the trees respond to the stimulus of overhead light with a rapid height growth. The difference in clear length is due entirely to the greater amount of side shade in the composite type.

Table 10, which is made from curves constructed upon the basis of age, shows to better advantage the differences in diameter growth of western yellow pine within the two types. It may be seen that up to the age of 110 years the diameter growth in the western yellow-pine type is greatest. But this is to be expected, since light conditions in the openings which characterize this latter type are more favorable than in the composite type, where there is a large amount of shade. At the age of 110 years the diameters are the same, but from this point on the growth in the composite type increases until at the age of 360 years there is a difference in diameter of 7.9 inches.

TABLE 10.—*Diameter growth of western yellow pine in two forest types.*

Age.	Diameter breast high outside bark.		Age.	Diameter breast high outside bark.	
	Composite type.	Western yellow-pine type.		Composite type.	Western yellow-pine type.
Years.	*Inches.*	*Inches.*	*Years.*	*Inches.*	*Inches.*
10	0.6	0.9	190	23.6	20.4
20	1.3	2.0	200	24.7	21.1
30	2.2	3.3	210	25.8	21.7
40	3.4	4.6	220	26.9	22.4
50	4.6	6.0	230	27.9	23.0
60	6.0	7.4	240	28.9	23.6
70	7.5	8.6	250	29.8	24.2
80	9.0	9.9	260	30.6	24.7
90	10.5	11.1	270	31.4	25.2
100	12.0	12.2	280	32.2	25.7
110	13.4	13.4	290	32.9	26.1
120	14.8	14.4	300	33.5	26.6
130	16.2	15.4	310	34.1	27.0
140	17.5	16.3	320	34.7	27.4
150	18.8	17.2	330	35.2	27.7
160	20.0	18.1	340	35.7	28.0
170	21.2	18.9	350	36.2	28.4
180	22.4	19.7	360	36.6	28.7

EFFECT OF CUTTING UPON REPRODUCTION.

To determine the rate of establishment and loss of seedlings of the different species during the early stages of development, and the controlling factors, a reproduction study was begun in the fall of 1910 on the cutting plots established within the composite type. Three reproduction plots ranging in area from 5,000 to 7,500 square feet were laid off, each within a cutting plot of from 1 to 2 acres in extent, cut under a specified system, and representative of a certain site or subtype of considerable area.

Permanent scribed stakes were set at the corners of each plot; smaller ones were placed along each end at intervals of 5 feet. By stretching steel tapes between corresponding stakes at opposite ends of the plot, and using strips of boards for cross lines, it was possible to do the counting and recording by plots 5 feet square. The kind, number, and age of all small reproduction was noted. In the case of larger seedlings and saplings, where the age could not be ascertained, the species was noted, and the height up to 10 feet recorded by foot classes. The location of all trees and stumps on or immediately adjacent to the plots, together with the size, species, etc., were likewise charted.

In order to determine the light requirements of the different species, several stations, each representing a different light intensity, were selected on each plot, and a series of light readings was taken during the clear weather in September, 1910, at every hour from 8 a. m. to 5 p. m., for a period of three days.

To determine whether or not a brush covering lessens the damage done by frost, both in the actual freezing of the tissues and in heaving

out of the ground, alternate strips in two plots were covered with brush.

Only one count has been made since the reproduction plots were established in 1910. While the data obtained for the single year are not sufficient to form a basis for definite conclusions, they are of some value in devising a system of management. It is intended that more counts shall be made on each reproduction plot, and if possible more light readings taken at the stations already established.

REPRODUCTION PLOT 1.

This plot is located within a stand of medium density on a level area at an altitude of 9,150 feet. The northern half is shaded during the greater part of the day by several large Douglas firs. Some spruce poles and several aspen saplings cast an appreciable amount of shade when in leaf. The southern half has much less shade, there being only one large western yellow pine. This part of the plot is covered with a dense growth of mountain bunch grass, which grows but sparsely on the other half. The soil is comparatively free from rocks, and consists of loam with a clay subsoil. Humus and leaf litter are found to some extent over the northern half of the plot, being thickest under the large trees and around the stumps cut in 1910. The average light intensity after cutting at five stations on this plot is 0.291.[1]

On this cutting plot a general selection system of cutting was practiced. All mature and overmature trees, as well as those which would become overmature within 40 years, were removed. Most of the healthy young trees, together with two standards, one Douglas fir and one yellow pine, were left for the production of seed. Since there is already an abundance of spruce reproduction, most of the trees of this species above a diameter of 12 inches were cut.

Although the western portion of the reproduction plot is shaded, and there are no yellow-pine seed trees on or near it, seedlings of this species predominated in 1910. Spruce and fir are found in greatest numbers where there is some protection from the sun. On the southern half of the plot, where the light intensity is greatest, spruce is entirely lacking and there are but few Douglas fir seedlings. Although western yellow pine germinates in this exposed situation, practically none of the seedlings were alive the second year. Reproduction, especially that of yellow pine, does not occur immediately around the base of the older trees and stumps. However, this is not the case under young spruce trees, which have broad crowns. While the absence of yellow pine reproduction may be due in part to the shade, it is largely accounted for by the depth of the litter, which makes a poor bed for the germination of the seed. In the yellow pine type

[1] 1.0 represents full light.

absence of reproduction directly beneath the crown, even where the seed bed is favorable, is attributed to adverse moisture conditions. However, such can not be the case in this type, since spruce seedlings are invariably found directly under the mother tree. In comparing the counts for 1910 and 1911 it was seen that a very large percentage of the seedlings of all species die during their first year of growth. This loss decreases with an increase in age. It is evident from these counts that yellow-pine seedlings will germinate but not grow for any length of time in direct sunlight.

Table 11 shows the number of living seedlings and the percentage of loss in each age class during the year 1910–11 for Reproduction Plot 1.

TABLE 11.—*Seedling counts on Reproduction Plot 1.*

Age.[1]	Number of living seedlings.								
	Western yellow pine.			Douglas fir.			Blue spruce.		
	First count (1910).	Second count (1911).	Loss.	First count (1910).	Second count (1911).	Loss.	First count (1910).	Second count (1911).	Loss.
Years.			*Per ct.*			*Per ct.*			*Per ct.*
1	360	17	95.2	147	2	98.6	13	1	92.3
2	1	1	.....	3	1	66.6	1	1	.....
3	5	3	40.0	17	11	35.3	2	1	50.0
4	14	10	28.5	35	16	54.3	2	1	50.0
5	6	6	.....	21	9	57.1	3	2	33.0
1 inch high and over	4	4	.....	20	18	10.0	27	27	.....
Total loss in seedlings 1 to 5 years old	.....	.....	90.4	.....	.....	82.5	.....	.....	71.4

[1] Refers to age at time of first count.

REPRODUCTION PLOT 2.

This plot comprises an area of 6,000 square feet, and is located within a cutting plot in a medium dense stand on a gentle southerly slope. Large trees of all species are evenly distributed over the area. The altitude is approximately the same as for plot 1. The soil is a black loam of good depth, and supports a medium stand of mountain bunch grass. The area is comparatively free from rocks. Like plot 1, humus and litter are present only under the large trees and around stumps. After the cutting was made the average light intensity at five stations on the plot was found to be 0.277.

The cutting system was the same as for plot 1. Inasmuch as there were a number of saplings and poles on the area, but few standards were left for the production of seed. One is within the reproduction plot.

It was noticed here, as in plot 1, that few seedlings germinate and grow in the litter and humus around the base of large trees. Table 12 gives for the year 1910–11 the number of living seedlings and the

percentage of loss in each age class for both the open and brush-covered areas. The figures for the total area correspond closely to those in Table 11 for Reproduction Plot 1. For all three species the loss on the brush-covered area is not so great as that in the open.

TABLE 12.—*Seedling counts on Reproduction Plot 2.*

OPEN.

Age.[1]	Number of living seedlings.								
	Western yellow pine.			Douglas fir.			Blue spruce.		
	First count (1910).	Second count (1911).	Loss.	First count (1910).	Second count (1911).	Loss.	First count (1910).	Second count (1911).	Loss.
Years.			*Per ct.*			*Per ct.*			*Per ct.*
1	165	3	98.2	54	3	94.4	49	1	97.9
2				3		100.0	6	1	83.3
3	2	1	50.0	9	4	55.0	5	2	60.0
4				2	1	50.0	2	2	
5				1	1				
BRUSH COVERED.									
1	90	5	94.4	18	2	88.8	14	1	92.8
2							1		100.0
3									
4				3		100.0	2	2	
5									
TOTAL AREA.									
1	255	8	96.8	72	5	93.0	63	2	95.2
2				3		100.0	57	1	85.5
3	2	1	50.0	9	4	55.5	25	2	60.0
4				2	1	50.0	2	2	
5				1	1				
1 inch high and over				15	15		18	17	5.5
Total loss in seedlings 1 to 5 years old			96.4			88.8			92.1

[1] Refers to age at time of first count.

REPRODUCTION PLOT 3.

Cutting Plot 3, within which is Reproduction Plot 3, is situated on a pronounced southwest slope at an altitude of 9,100 feet. In spite of the fact that the exposure is unfavorable, this slope is covered with an exceptionally dense stand of timber in which Douglas fir predominates. Before cutting there were several western yellow pines of all sizes and a few spruce, none of the latter over 18 inches in diameter. The reproduction plot on this subtype has an area of 5,950 square feet. The soil is largely clay, and is covered with a scant stand of grass. A small proportion of the area would be classified as rocky. There is some humus and litter. The average light intensity at the five stations marked on this plot is 0.439.

The silvicultural system practiced on Cutting Plot 3 was a combination of the selection and diameter limit methods. Since indications pointed to the fact that Douglas fir and blue spruce reproduced more satisfactorily than western yellow pine in a stand of this kind, the latter species was cut under selection method, while spruce and fir were cut to a 12-inch diameter limit. In this way it was sought to open up the stand enough to check the reproduction of the tolerant species, and at the same time favor the intolerant one. Future seed crops of pine were insured by leaving several medium-sized trees. All the mature and overmature yellow pines were removed. Spruce and fir usually produce sufficient seed when from 10 to 12 inches in diameter. It is recognized that such small plots as are dealt with in this study will be greatly influenced by the surrounding stand, and that therefore the method of cutting can have but little influence upon seed supply and protection from wind. The method of cutting will, however, influence light conditions, an important factor in the regeneration of a stand of this character.

LOSS IN SEEDLINGS.

Table 13, based upon the seedling counts on Reproduction Plots 1 and 2, shows the loss in seedlings during the first four years of growth. It may be seen that the greatest loss occurs during the year following germination, and that the rate of loss decreases from year to year. From the trend of the figures it is evident that the percentage of loss which occurs after the sixth or seventh year is very small as compared to that in the early stages of development.

TABLE 13.—*Loss in western yellow pine, Douglas fir, and blue spruce seedlings from 1 to 5 years old.* [1]

Period.	Loss.		
	Western yellow pine.	Douglas fir.	Blue spruce.
	Per cent.	*Per cent.*	*Per cent.*
From first to second year	96.0	96.8	96.0
From second to third year	.....	83.3	75.0
From third to fourth year	42.8	42.8	57.1
From fourth to fifth year	28.5	54.0	25.0

[1] This table is based upon seedlings 2, 3, and 4 years old, as well as those 1 year old at the time of the first count.

FACTORS WHICH AFFECT LOSS.

Light is one of the most important factors in the germination and growth of forest seedlings. While conclusive light studies have not yet been carried on within this type, it is evident that yellow pine seedlings require a greater light intensity than either Douglas fir or blue spruce, and that in early life Douglas fir requires more light

than blue spruce. The light requirements for each species change with an increase in age. After the seedling stage is passed trees of all species make a better growth when full light is received.

The great loss during the first year is due largely to the fact that germination does not take place until after the summer rainy season begins, with the result that the seedlings are very tender when freezing weather sets in. While the low temperature may have some effect upon the tissues of the plant, the greatest amount of damage is done by heaving. If the soil is wet the loss from this source is apt to be great; if dry, there is little or no damage done. By the fall of the second year the roots penetrate more deeply into the soil, and the loss from this cause is materially lessened.

It appears that a brush covering decreases the loss in 1-year-old seedlings. This is due to the moderating influence of the cover upon extremes of temperature, and upon alternate freezing and thawing.

The effect of heat at this altitude, and especially within the dense stands of the composite type, is thought to be of secondary importance. There is usually a cover of grass to protect the young seedlings from the direct rays of the sun when they are not shielded by tree growth.

While it is not known how much loss results from drought, the number of seedlings in the composite type which die from this cause is probably lower than in the pure yellow type. The longest period of drought occurs in the spring of the year. The heavy snows do not melt until April, and since evaporation is checked by the dense stand, it is likely that the soil seldom loses all the moisture available for seedling growth before the beginning of the summer rainy season.

MANAGEMENT.

The composite type has its greatest value as a source of saw timber. Mine stulls and lagging will no doubt be exploited, provided the roads which open up the body of timber make direct connection with the mining districts of southern Arizona.

METHOD OF CUTTING.

The combination of the three species found in the composite type is one which should be perpetuated. No other species or combination native to the region is better fitted to satisfy the objects of silviculture. As the result of differences in light requirements of the three species the growing space is well utilized, making possible a yield more than twice as great as in the average forest of pure yellow pine, while the density of the stand greatly increases the quality of the lumber obtained.

The clear length of western yellow pine is from 16 to 25 feet greater in the composite than in the yellow-pine type. That of Douglas fir

compares favorably with this. Spruce is more limby, and from an economic standpoint inferior, but its extreme tolerance renders it of great value in cleaning the other species. It seldom comes in where either yellow pine or Douglas fir would grow.

Since the silvical requirements of western yellow pine, Douglas fir, and blue spruce are different, especially in regard to light, it is necessary, in order to maintain their growth in mixture, to employ a selection method of cutting. For such a method only broad rules can be outlined which in a general way will suit the conditions and serve as a basis for more detailed studies.

Over most of the type are western yellow pine and Douglas fir of all ages, from the seedling to the veteran stage; spruce is commonly found up to the age of 150 years. As far as age is concerned, therefore, the type is uniform, but the proportion in which the different species occur varies widely. Upon this, in any given situation, depends the amount of timber of each kind which should be removed, and that species, if any, which, on account of its limited occurrence, should be favored.

All mature and overmature timber should be removed, together with that still making a good growth, but which would be overmature at the time of a second cut. All thrifty Douglas fir and yellow pine which will plainly be of more value in the future should be left standing. Spruce, on areas suited to yellow pine and Douglas fir, should be cut to the lowest diameter limit from which merchantable material of any kind can be obtained, except where its presence would cause pine and fir to prune themselves. In the spruce-pine subtype the aim should be, in the main, to produce yellow pine saw timber in connection with spruce poles and stulls. In the spruce-fir subtype the cutting should be regulated so that each species yields the best class of material for purposes to which it is particularly adapted.

The proportion of the stand to be left uncut will depend largely upon local conditions. Enough trees must be left standing to insure seed for future crops and to serve as a protection to young growth not yet established. Since there is timber of practically all ages, trees below the merchantable diameter limit will as a rule furnish sufficient protection to young growth. Merchantable yellow pine and Douglas fir left because of their greater value at the time of a second cut will in most cases furnish enough seed. Spruce commonly produces seed at diameters of from 8 to 12 inches. Only where reproduction is insufficient or where protection is needed should mature or nearly mature seed trees of any species be left standing. Broadly speaking, trees of all species above 29 inches and most of those between 20 and 29 inches in diameter should be removed. The number of trees under 20 inches in diameter cut depends chiefly upon the density of the stand. In dense stands of young trees, which are not infrequent,

a thinning should be made, and, if it can be done without too great expense, trees down to a diameter of 12 inches removed. Trees of inferior species should be discriminated against. Except where there is no competition from more valuable species, white fir and Mexican white pine should be cut to the lowest diameter limit at which they can be utilized. Unhealthy trees of all species which seem likely to die before the second cut should be removed. No insect-infected or diseased trees should be left standing, even though valueless. From one-half to two-thirds of the present merchantable stand can safely be removed. If this is done, and taking into account increased growth after cutting, a second cutting can be made in from 40 to 50 years. The amount of timber to be removed at this time will not be as great as at the first cutting, because there will be practically no overmature trees. However, the percentage of growth for the stand will be greater.

ROTATION.

To determine definitely the rotation for a virgin stand, it is necessary to know not only the number of trees per acre of each diameter class which will be left after cutting, but also those which will die from the effects of lumbering and shading before the time of a second cut. The rate of growth after cutting is also desirable. Since, however, only a part of this data is available for the composite type, the rotation can be determined only tentatively.

The objects of management should of course determine the kind of rotation. Since the aim in this type is to produce the greatest amount and best quality of lumber and to utilize the inferior species and parts for poles, stulls, and lagging, the financial rotation should be employed. The rotation under which the forest yields the highest net returns is well suited to the regeneration of the species.

However, there is a great difference between the financial rotation and the rotation of the greatest volume production. The latter coincides with the year in which the mean annual increment culminates. By referring to Table 8 it will be seen that the mean annual increment of yellow pine is still increasing at the age of 360 years. Neither has the mean annual increment reached its maximum in Douglas fir at the age of 320 years nor in spruce at the age of 150 years. Furthermore, the mean annual growth of each species will increase until that time when it is equaled by the current annual growth. Figure 4 shows the age of each species at which the mean annual growth equals the current annual growth. This for western yellow pine is seen to be 377 years, for Douglas fir 382 years, and for spruce 240 years. A rotation of this length would no doubt be satisfactory, provided there were no factor of loss to be taken into account. But in a forest of this age the annual loss from windfall and decay would probably amount to as much as the total yearly growth. Obviously

the rotation of the greatest volume production is out of the question if the financial aspect is considered. Since there is a difference in the rate of growth for yellow pine, Douglas fir, and blue spruce the rotation for each species must be considered separately.

WESTERN YELLOW PINE.

In yellow pine the minimum diameter from which a good grade of saw timber can be obtained is about 20 inches, though the value of timber from a 25-inch tree is considerably greater. Table 5, page 22, shows that the average pine 25 inches in diameter is 202 years old and contains 4.6 logs scaling 710 board feet. Eighteen years later, at a diameter of 27 inches, there are five logs scaling 920 board feet. From Table 8 it is seen that at the age of 200 years the periodic annual growth is 1.5112 cubic feet—only slightly less than at the time of culmination 60 years later. The periodic annual growth is 1.26 per cent, but rapidly decreasing. In view of these facts and since the decay after 220 years would probably to a large extent offset the growth, a rotation between 200 and 220 years seems advisable.

DOUGLAS FIR.

Douglas fir of a given diameter does not contain as many board feet as yellow pine of the same size. This is due to its lower form factor and to the greater thickness of its bark. However, volume growth as compared to age is practically the same for the two species. From Table 5 it may be seen that the average Douglas fir 28 inches in diameter contains 720 board feet, and one 29 inches, 800 board feet. These diameters are reached at the age of 202 and 210 years, respectively. Table 8 shows the mean annual growth at 210 years to be 0.6751 and the periodic annual growth to be 1.5123 cubic feet. The latter at this point is increasing, which shows that it is near the point of culmination. The annual growth at this time is 1.12 per cent. Taking into consideration decay, which after this period no doubt largely offsets the growth, it appears that the rotation for Douglas fir should be set at about 210 years, or approximately the same as that for yellow pine.

BLUE SPRUCE.

Since blue spruce should be used principally for poles and stulls, and in view of the fact that large trees are invariably affected with butt rot, the rotation will be comparatively short. While growth figures are not available for trees older than 150 years, it is plain that the maximum rate of growth occurs before this age is reached. At 130 years of age the average spruce is 22 inches in diameter and 98 feet tall. At 140 years it is almost 23 inches in diameter and has a total height of 104 feet. While its board foot content at this size is less than 400 feet, it will yield several stulls, or from one to two stulls and a pole. Since spruce will be less valuable for saw timber than for other purposes, it would not be profitable to allow this species to grow

to a greater diameter than 22 or 23 inches. The rotation, then, should not be longer than 140 years; and, should it be possible to dispose advantageously of small sized material, might be 130, or even 120 years.

BRUSH DISPOSAL.

Over most of the type there is an excellent stand of young growth. On these areas the brush should be piled. Where the degree of exposure is great and where young growth is deficient, the brush should be lopped and scattered. If there is great danger from fire, however, this plan should not be rigidly adhered to. In such cases the brush on narrow strips should be piled and burned.

FIRE.

The rank growth of grass over all of the type makes ground fires likely at certain periods of the year. The large amount of precipitation, however, greatly lessens the danger. The only times of danger are short periods in the spring and fall. In the former, there is a dry period from the time the snow melts until the summer rainy season begins; and in the latter, from the end of the rains until snow falls. The occurrence of fire in this latter period, however, is less probable, since frost results in the grass being saturated for several hours during the early part of each day.

In the case of a ground fire, seedlings of all species will suffer greatly. But few yellow pine and Douglas fir above the seedling stage will be seriously damaged, due to the resistant character of their bark. Spruce is more susceptible, and cases have been noted where saplings and small poles of this species were killed outright by ground fires where no appreciable damage was done either yellow pine or Douglas fir. Likewise in spruce standards the scars from fires are likely to be more serious, and probably often result in decay or death, a result seldom seen in yellow pine or Douglas fir.

The danger from fire after cutting will be greatly increased by the large amount of inflammable slash. As a rule, fire lines should be burned. These are especially necessary where the brush has been scattered.

GRAZING.

As long as reproduction is sufficient, grazing within the composite type should not be restricted, though it is important that it be regulated at all times. Because of the excellent forage conditions there is at present little or no damage done to reproduction by either sheep or cattle. In view of this fact, and since the heavy stands of grass remaining in the fall enhance the fire danger, areas within the type should be grazed closely, but not beyond the point where there is danger of depleting the range or of damaging the seedling growth.

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